3.155J/6.152J Lecture 7: MEMS Lab Overview

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Massachusetts Institute of Technology

10/3/2005

Outline

- MEMS Device and Technology Overview
- Anisotropic Etching
- Description of the Process and Testing
- Silicon Nitride as a Mechanical Material
- References
    - Senturia, Microsystems Design, Kluwer

MEMS Manufacturing Technologies

- Bulk Micromachining
  - DRIE-Based
  - Wet Processes
- Surface Micromachining
- Wafer Bonding
  - Front end – e.g. Fusion Bonding
  - Back end – e.g. Anodic Bonding
- Plastic Processes
  - Molding
  - Embossing
- Others
  - High Aspect Ratio Metals (LIGA)
  - EDM

Micromachining

Figures removed for copyright reasons.

Please see: Figures can be found in slide 10 of Tang, W. "MEMS Programs at DARPA." Presentation, DARPA, http://www.darpa.mil/mto/mems/presentations/memsatdarpa3.pdf

W. Tang - DARPA

Deep Etch Micromachining

Figures removed for copyright reasons.

Neural Probes

Figures removed for copyright reasons.

http://www.cyberkineticsinc.com/content/index.jsp

Bulk Micromachining: Wet Etching

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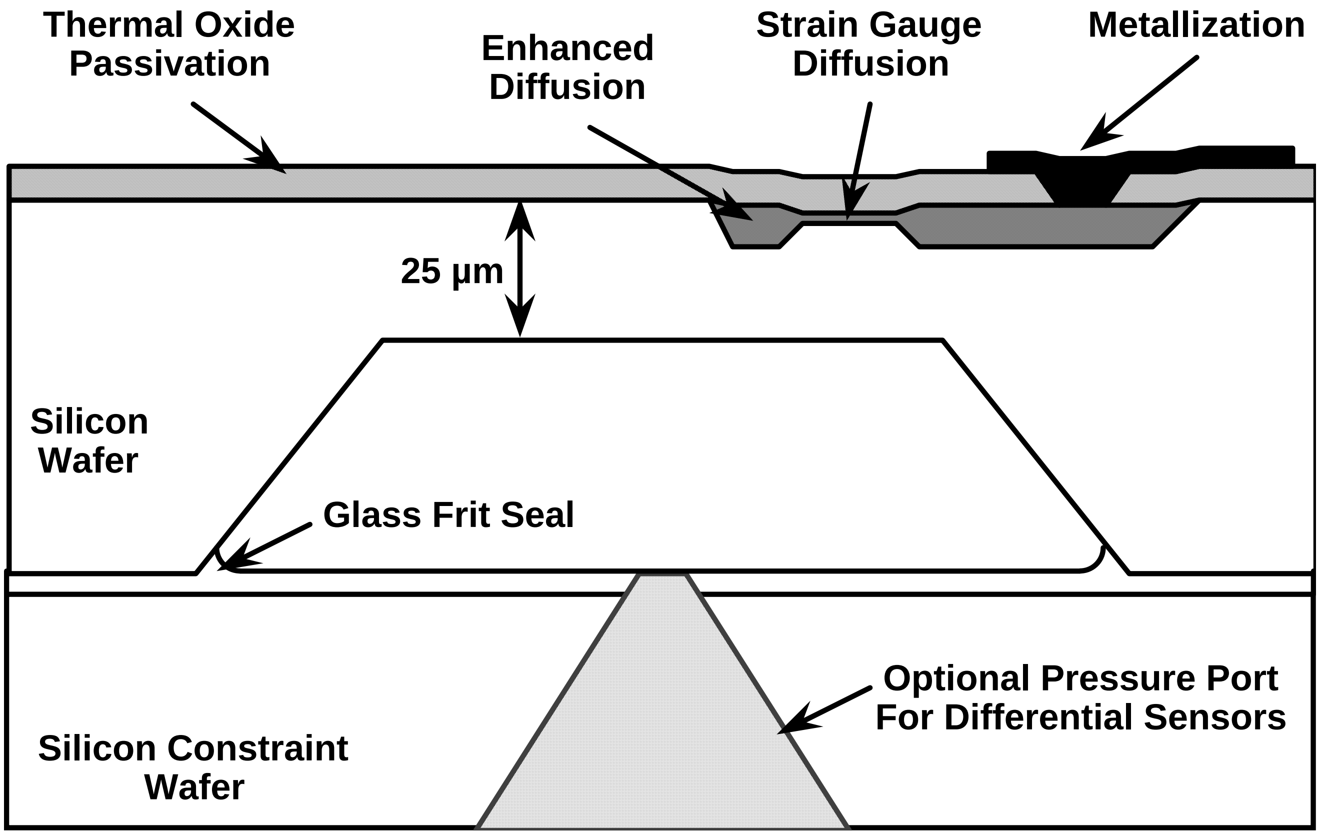
Please see: Figures can be found in slide 9 of Tang, W. "MEMS Programs at DARPA." Presentation, DARPA, http://www.darpa.mil/mto/mems/presentations/memsatdarpa3.pdf

W. Tang - DARPA

Pressure Sensors



Microphones and Pressure Sensors

Figure removed for copyright reasons.

See http://www.emkayproducts.com/html/sil_mic.html

Figure removed for copyright reasons.

NovaSensor

Ink Jet Nozzles and Heater Chips

- In development since 1973
- Today: 1.5 million produced <u>every day</u>
- HP and Lexmark use **Si heater chips**
  - laser-cut **polymer** nozzles
- Canon uses Si MEMS nozzles
  - “edge shooters” with bonded Si wafers

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Drug Delivery

Figures removed for copyright reasons.

Figure removed for copyright reasons.

Please see: Figure found in J.T. Santini, Jr., M.J. Cima, and R. Langer. "A controlled release microchip." *Nature* 397 (Jan 28, 1999): 335-338.

Surface Micromachining

Figures removed for copyright reasons.

Please see: Figures can be found in slide 11 of Tang, W. "MEMS Programs at DARPA." Presentation, DARPA, http://www.darpa.mil/mto/mems/presentations/memsatdarpa3.pdf

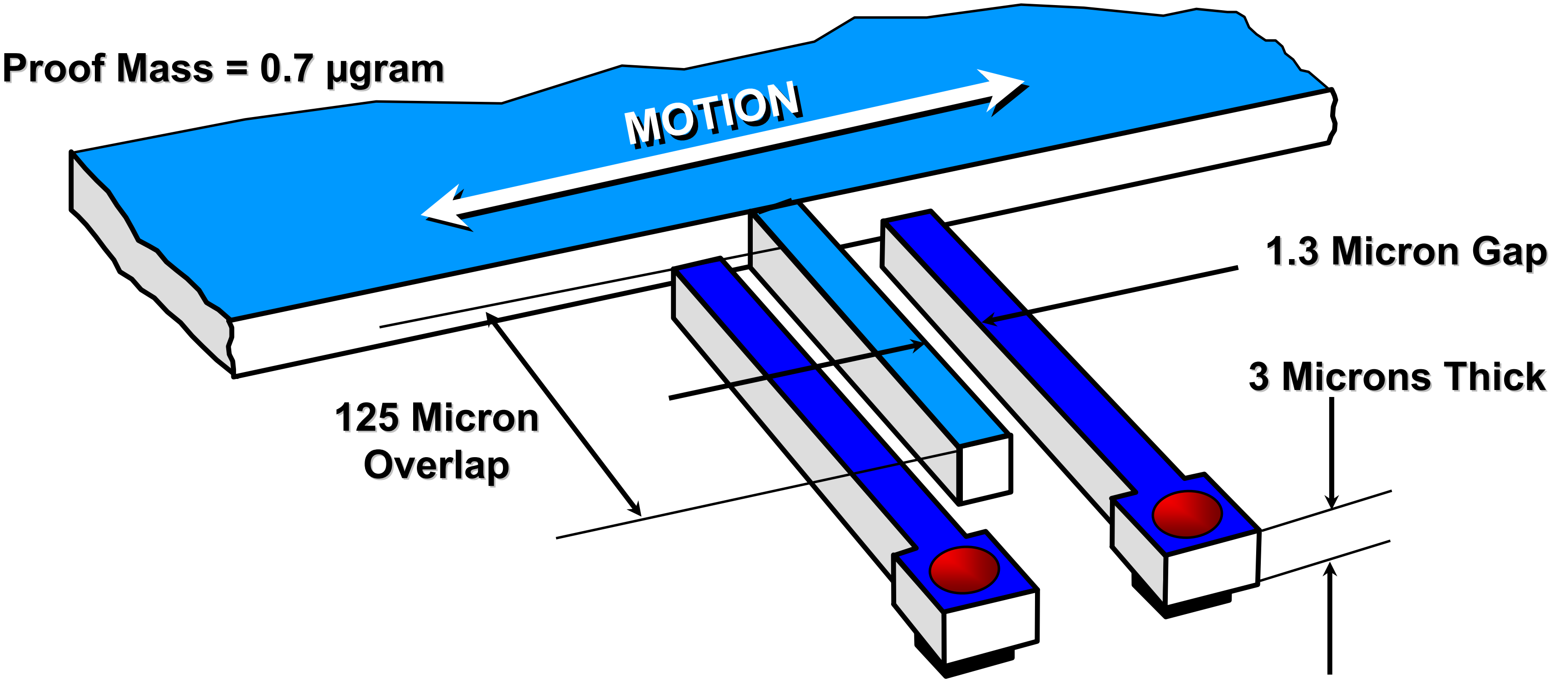
W. Tang - DARPA

Polysilicon Surface Micromachining

Figures removed for copyright reasons.

Dynamic Silicon

Micromachined Accelerometers and Gyros



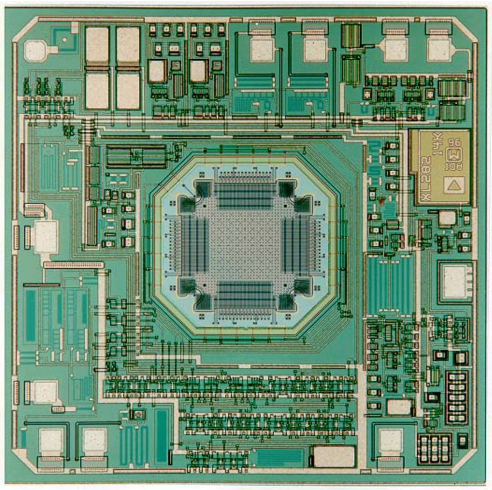
- **This is a single finger set. There are 30 sets per axis**

R. Sulouff

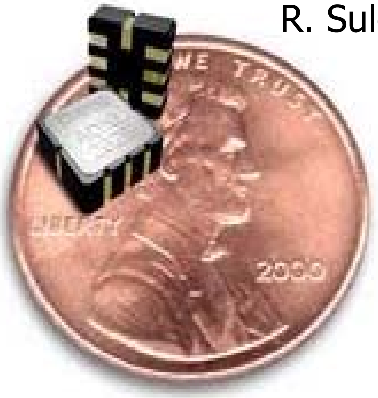
Courtesy of Robert Sulouff, Analog Devices. Used with permission.

ADXL 202 Brings Robots to Life

Photo of toy robot dogs
removed for copyright reasons.



R. Sulouff



Courtesy of Robert Sulouff, Analog Devices. Used with permission

Gyroscopes (Draper)

Figure removed for copyright reasons.

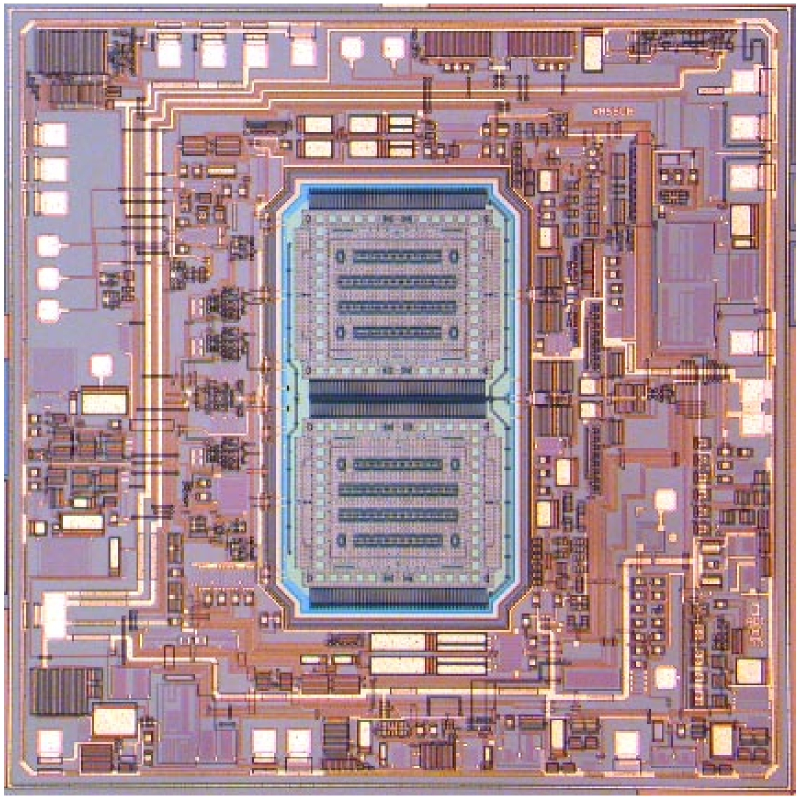
Please see: Figure found in Reference: J. Bernstein, S. Cho, A. T. King, A. Kourepenis, P. Maciel, and M. Weinberg, "A Micromachined comb-drive tuning fork rate gyroscope". *Proc. IEEE Micro Electro Mech. Systems* (1993): 143.

Analog Devices Gyro

Single Chip Rate Sensor

5V Operation
Std Atmosphere
150 deg per second
Self-Test
0.03 deg/sec/sqrt hz
Compensated 5%

Gyro Chip



Courtesy of Robert Sulouff, Analog Devices, Used with permission

R. Sulouff

Displays

Figure removed for copyright reasons.

Please see: Figure 19 in Hornbeck, L. "Digital Light Processing: A New MEMS-Based Display Technology." White Paper, Texas Instruments.

TI Micro-Mirror
Display :
> 1M moving parts

Figure removed for copyright reasons.

Please see: Figure 19 in Hornbeck, L. "Digital Light Processing: A New MEMS-Based Display Technology." White Paper, Texas Instruments

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Surface Micromachined Gears

Figures removed for copyright reasons.

Please see: Figures 3 and 8 in Mehregany, M., K. Gabriel, and W. Trimmer. "Integrated Fabrication of Polysilicon Mechanisms." *IEEE Transactions on Electron Devices* 35, no. 6 (1988): 719-723.

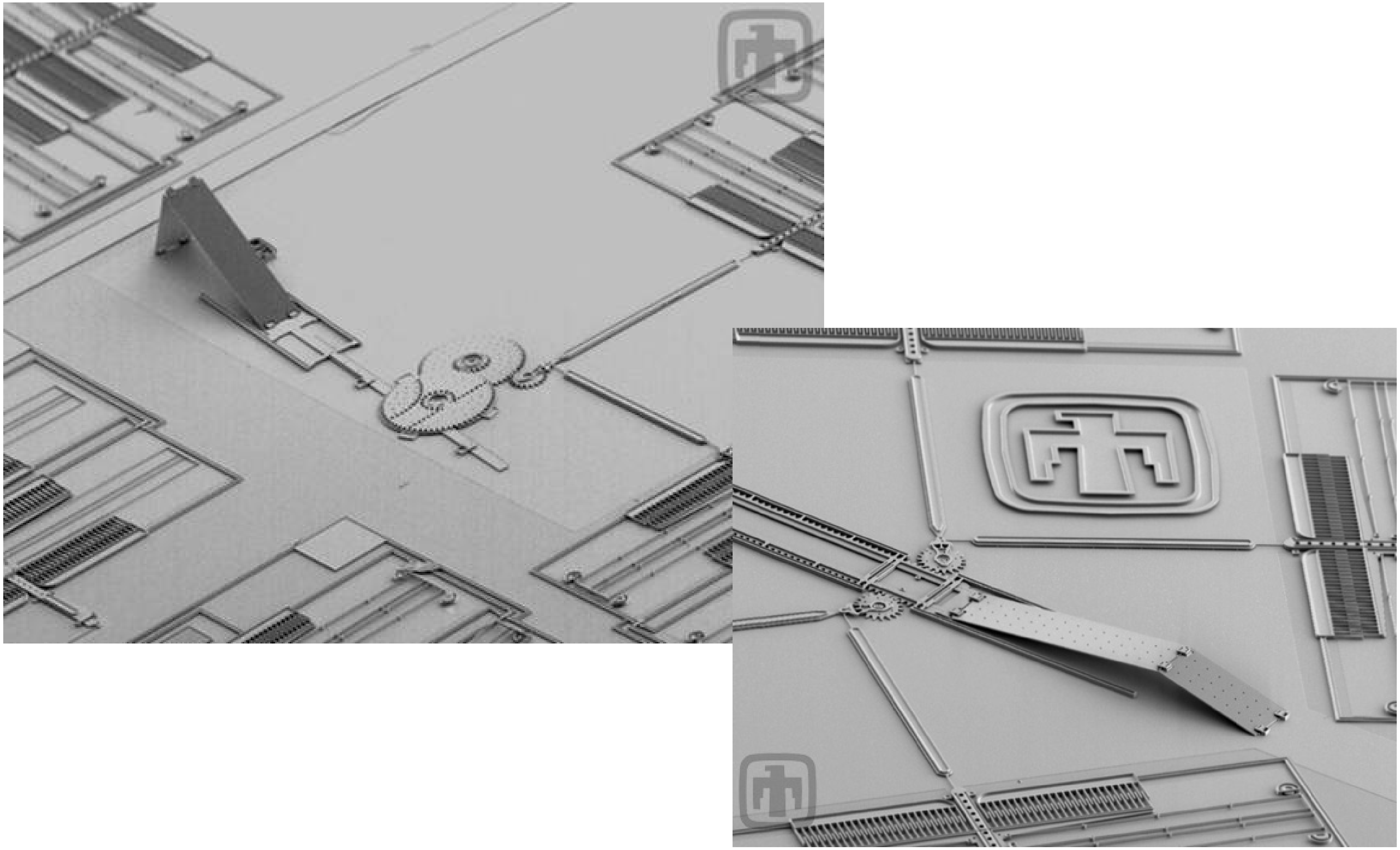
M.Mehregany – Bell Labs

Pop-Up MEMS

Figures removed for copyright reasons.

K. Pister – UC Berkeley

Sandia MEMS



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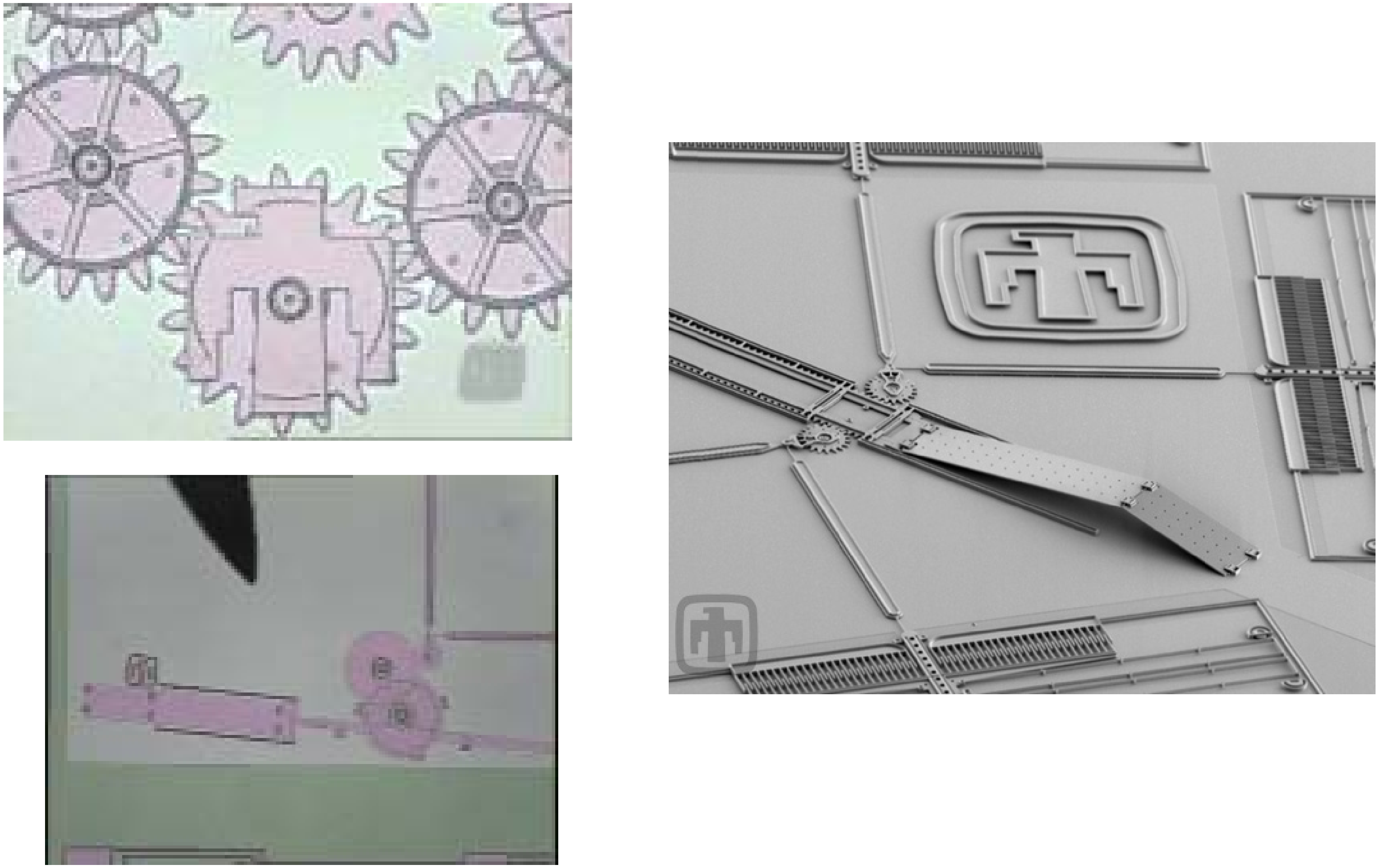
Sandia Gears



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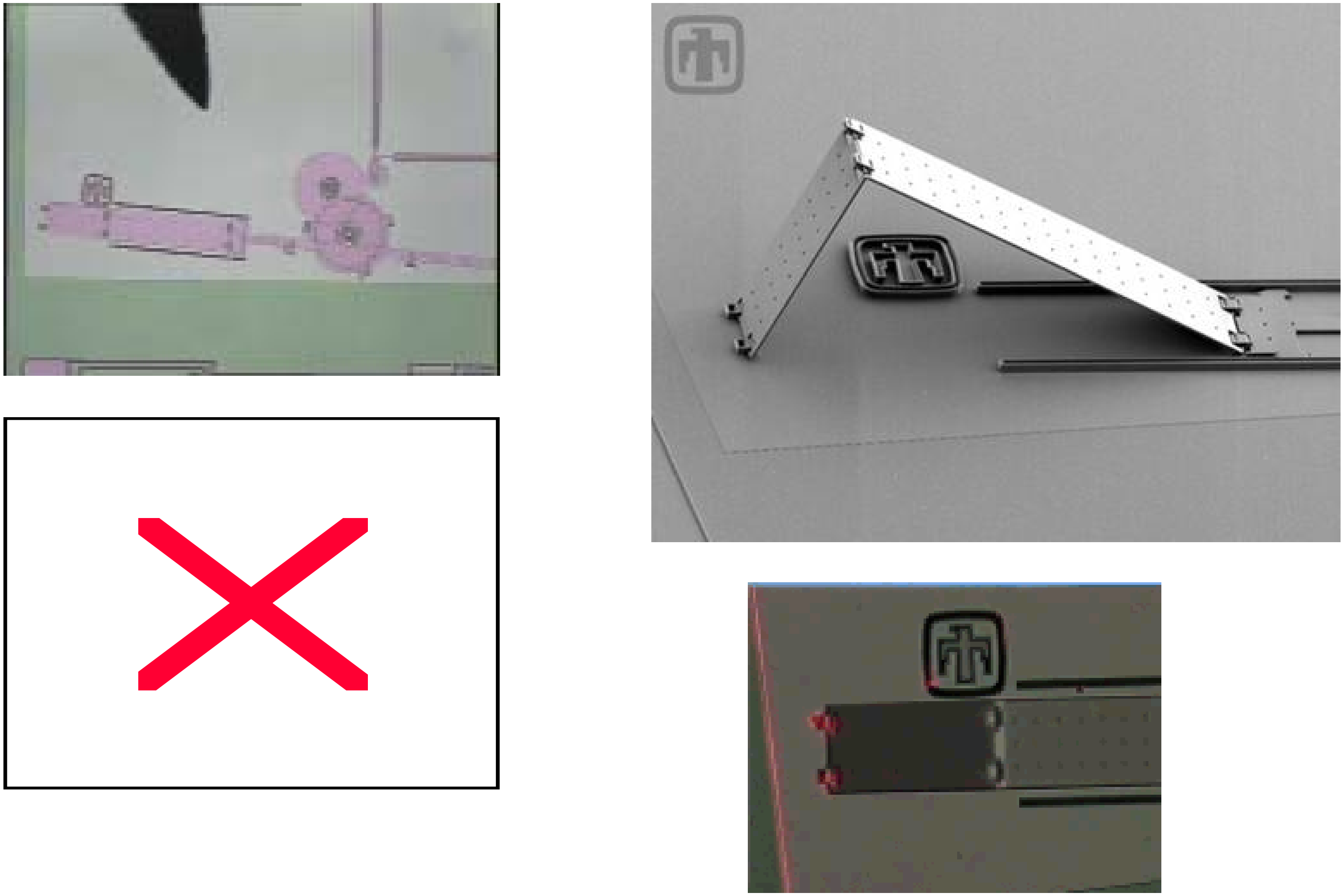
Sandia Mirrors



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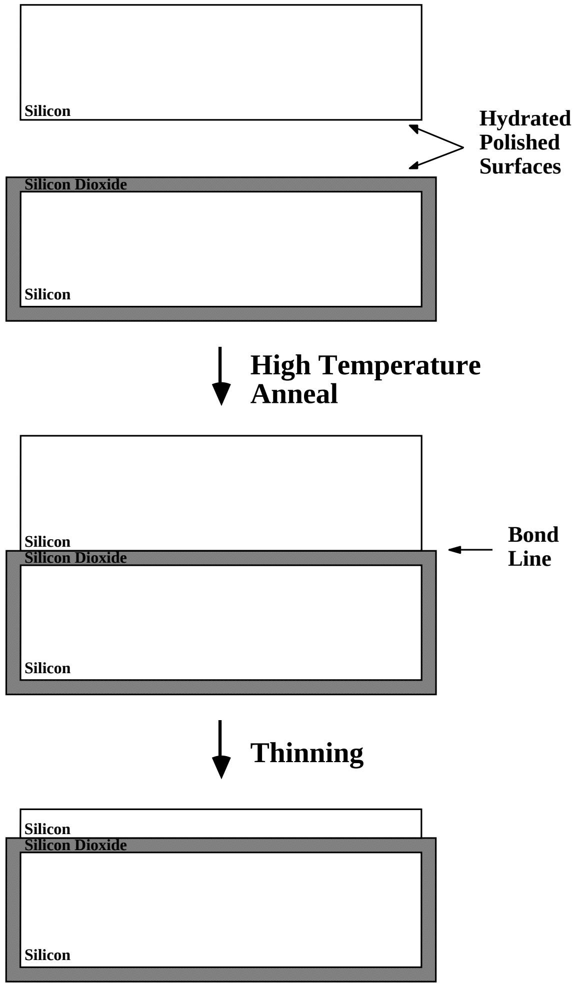
Wafer Bonding



Pressure Sensor

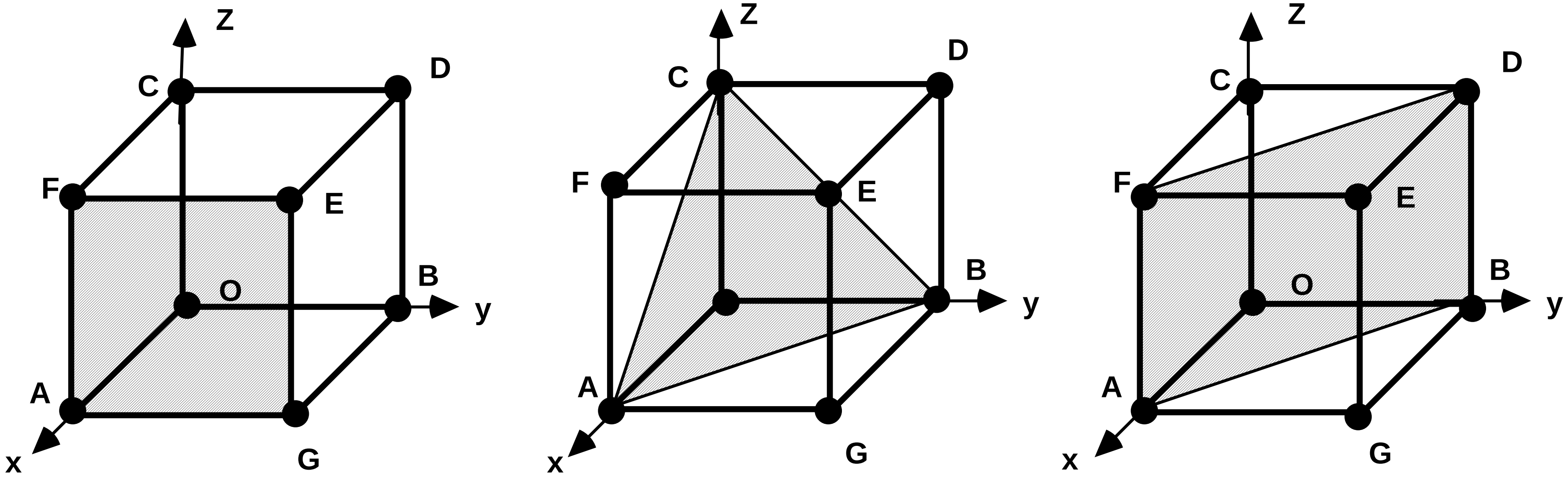
Figures removed for copyright reasons.

NovaSensor

MEMS Applications

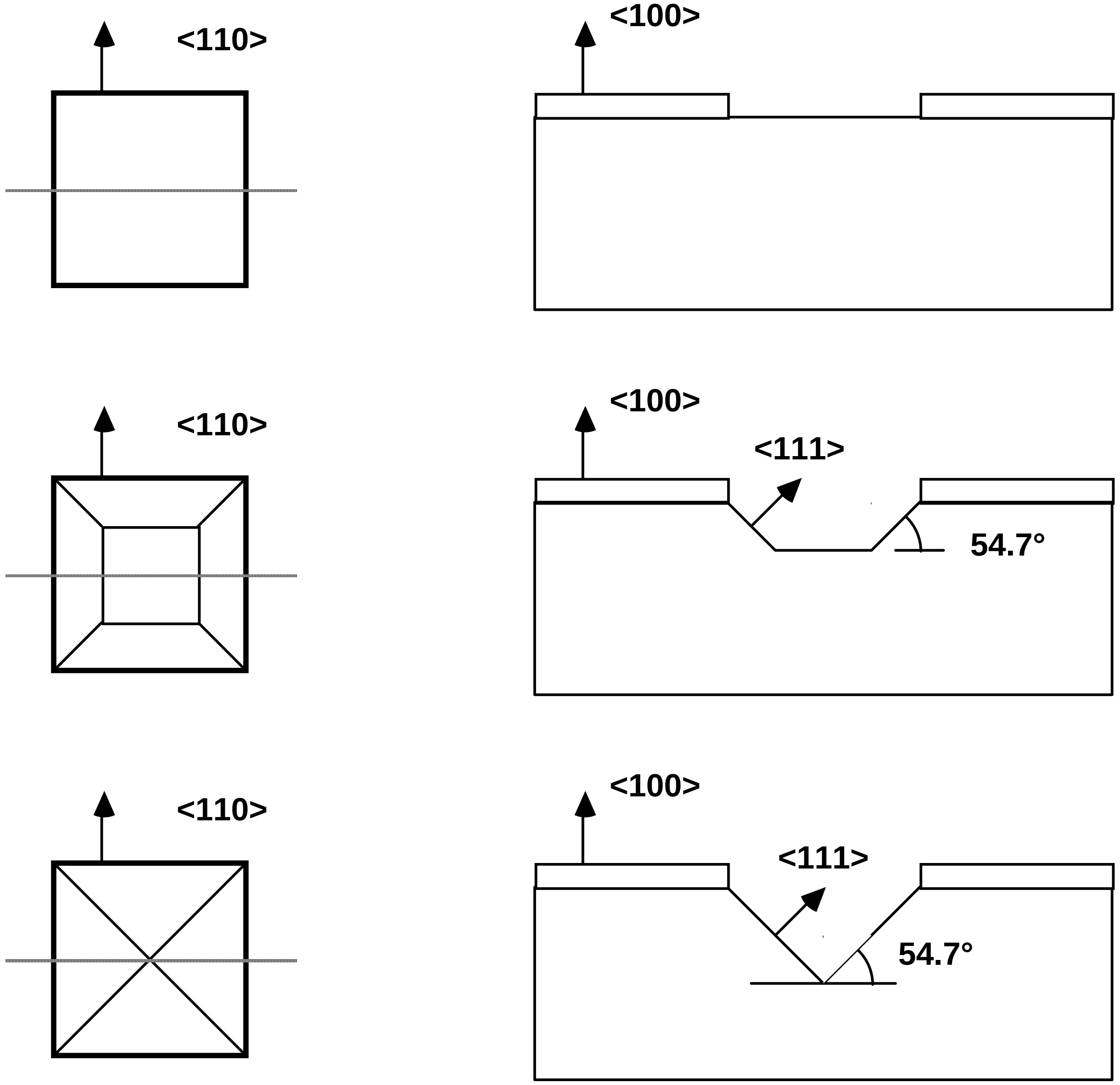
- Mechanical Sensors
  - Pressure, Acceleration, Flow (Mature)
    - Opportunities in wireless systems (μAmps, Smart Dust)
  - Acoustic
- Optical
  - Mirror Arrays
  - Modulators, Filters, Tunable Lasers
- Bio/Chem
  - Medical Instruments
  - Lab on a Chip (Chemical Sensors)
  - DNA/Protein Filters
  - Array-based Assays
- RF
  - Mechanical Filters
- Power
  - Energy Scavenging
  - Fuel Burning

Crystal Planes

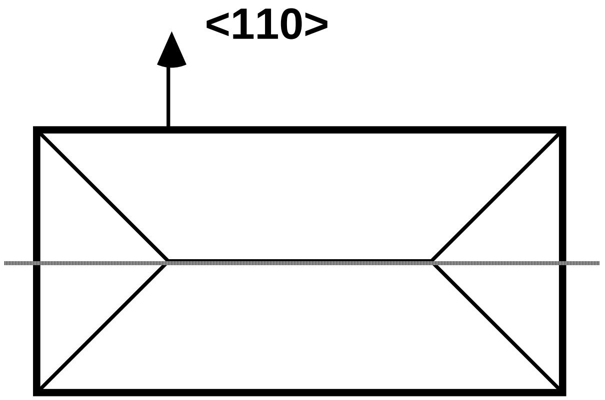


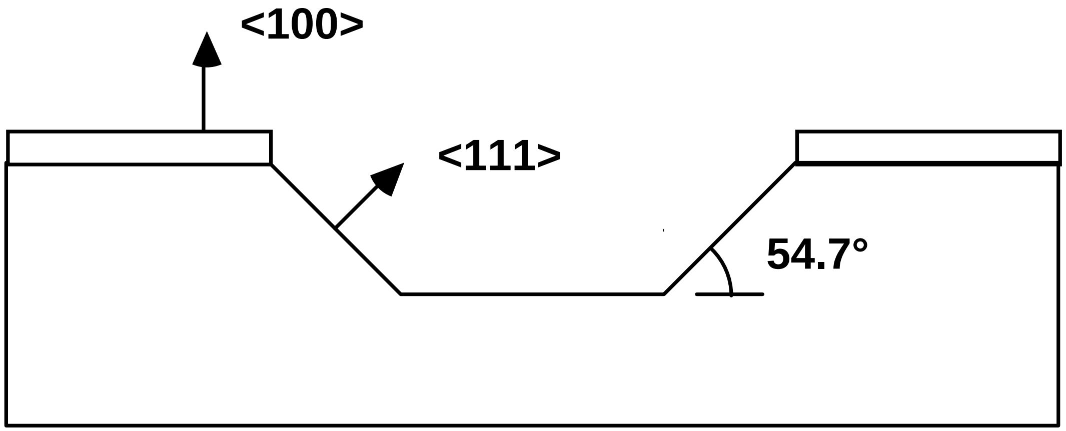
The family of planes AFEG (1,0,0), ABC (1,1,1) and ABDF (1,1,0)

Anisotropic Etching

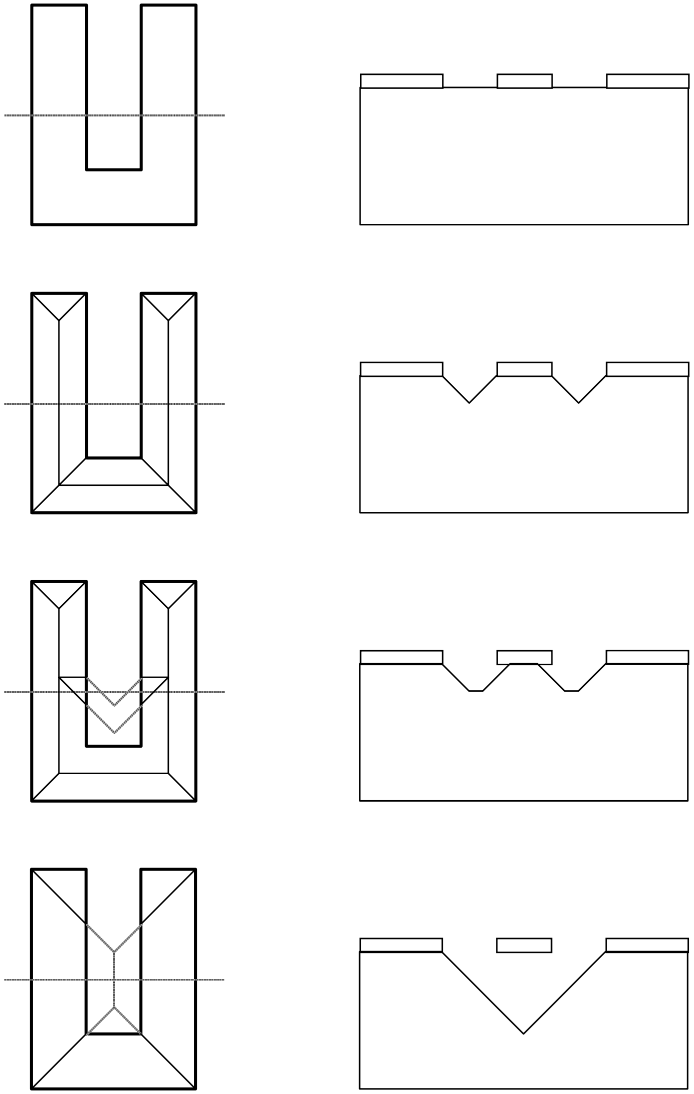


Grooves

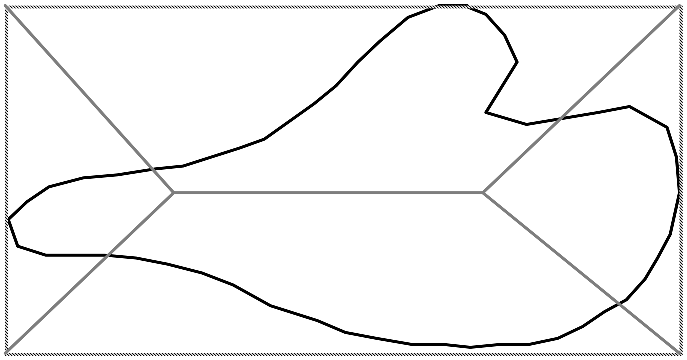


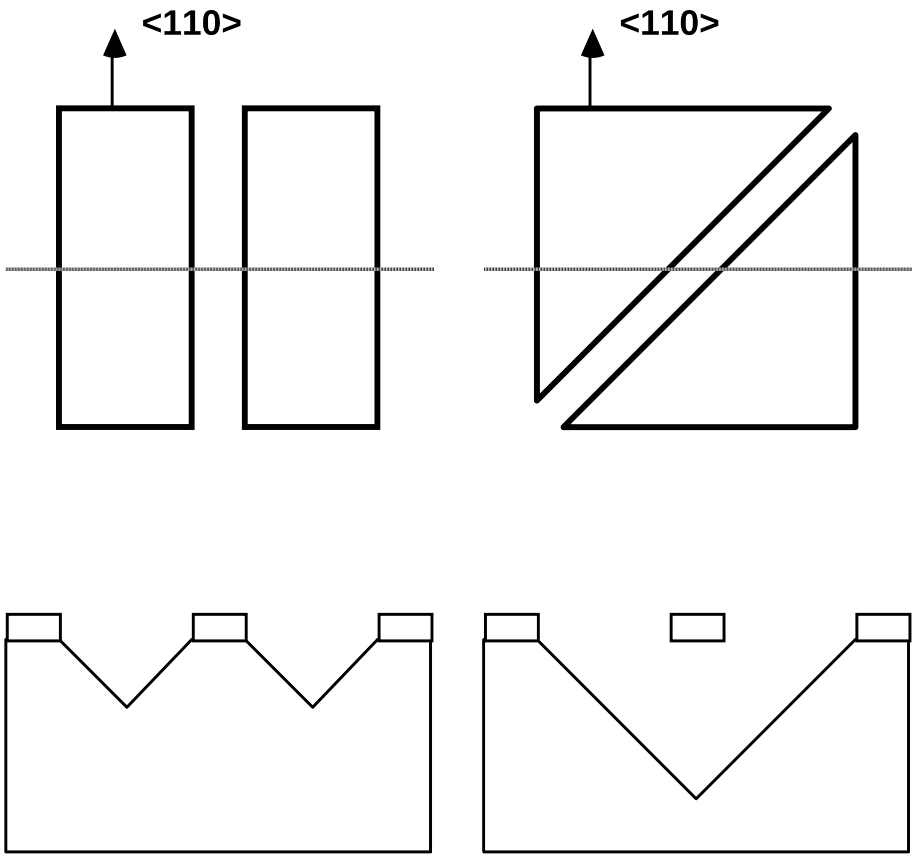


Anisotropic Etching



Anisotropic Etching





Anisotropic Etching

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Images found in Mehregany, M. "Application of Micromachined Structures to the Study of Mechanical Properties and Adhesion of Thin Films." *Master of Science Thesis*, Massachusetts Institute of Technology, May 23, 1986.

Anisotropic Etching

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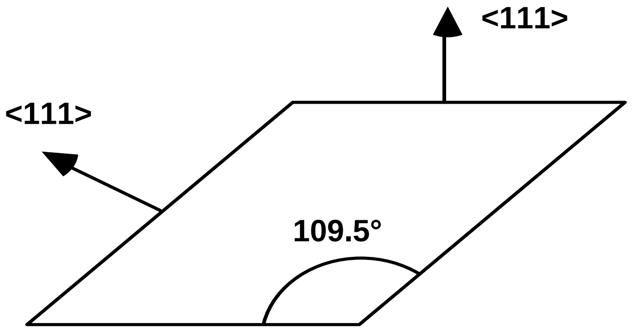
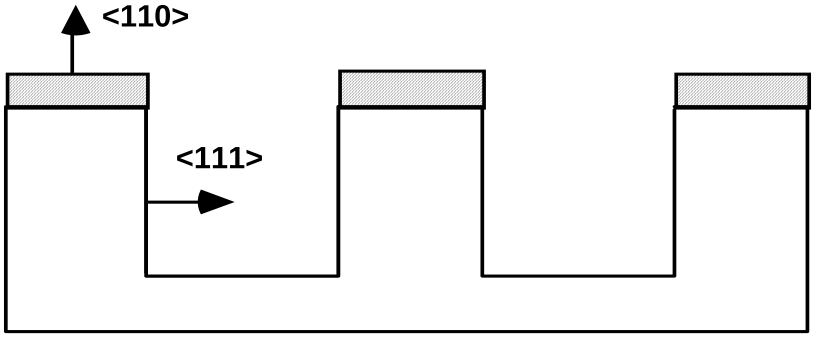
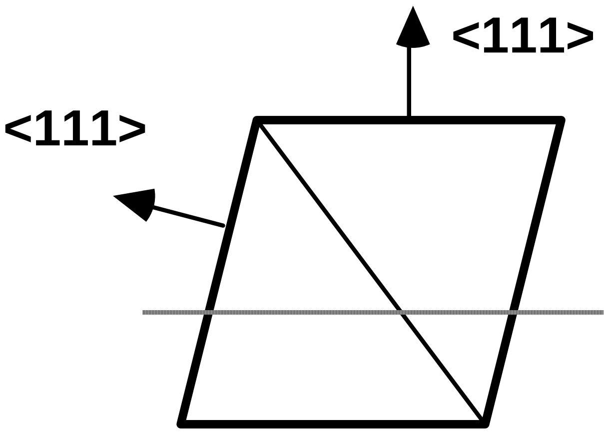
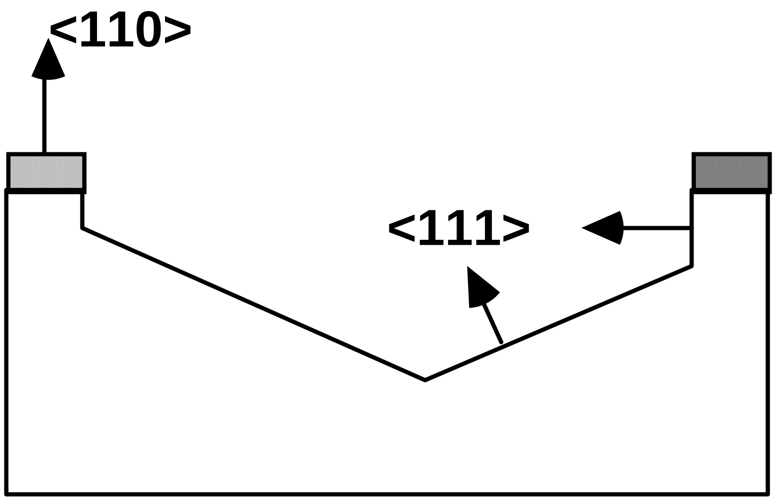
Images found in Mehregany, M. "Application of Micromachined Structures to the Study of Mechanical Properties and Adhesion of Thin Films." *Master of Science Thesis*, Massachusetts Institute of Technology, May 23, 1986.

<110> Silicon









Etch Rates

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Figure found in H. Seidel, L. Csepregi, A.Hueberger, and H. Baungärtel. *The Journal of the Electrochemical Society* 137 (1990): 3612-3626.

Orientation Dependence

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Figure found in H. Seidel, L. Csepregi, A.Hueberger, and H. Baungärtel. *The Journal of the Electrochemical Society* 137 (1990): 3612-3626.

Etch Masks

Si_3N_4 etch rate in most anisotropic etchants is virtually zero.

Figure removed for copyright reasons.

Figure found in H. Seidel, L. Csepregi, A.Hueberger, and H. Baungärtel. *The Journal of the Electrochemical Society* 137 (1990): 3612-3626.

Si/SiO$_2$ Etch Rate Ratio

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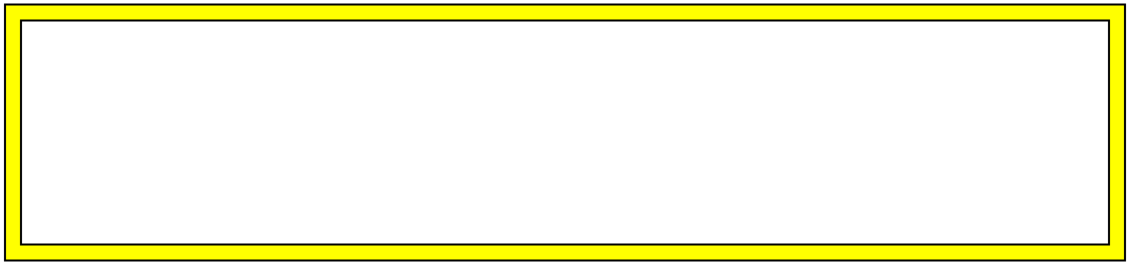
Figure found in H. Seidel, L. Csepregi, A.Hueberger, and H. Baungärtel. *The Journal of the Electrochemical Society* 137 (1990): 3612-3626.

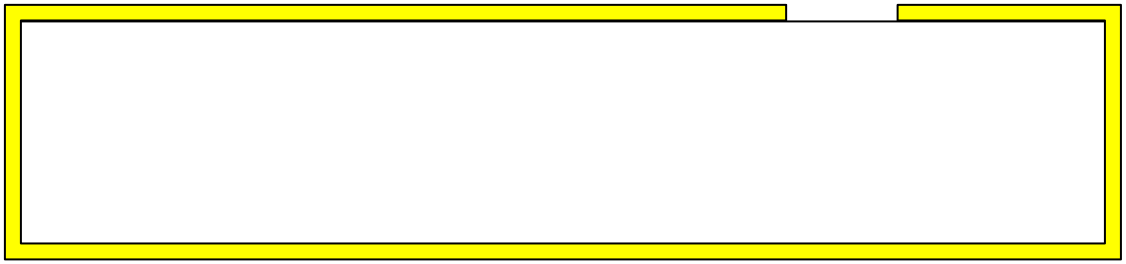
The Process – Lab 1

- Grow 1.0μm of Si-Rich Silicon Nitride (SiN_x)
  - LPCVD Process (performed before lab)
  - Characterize (UV1280)
    - Thickness
    - Refractive index



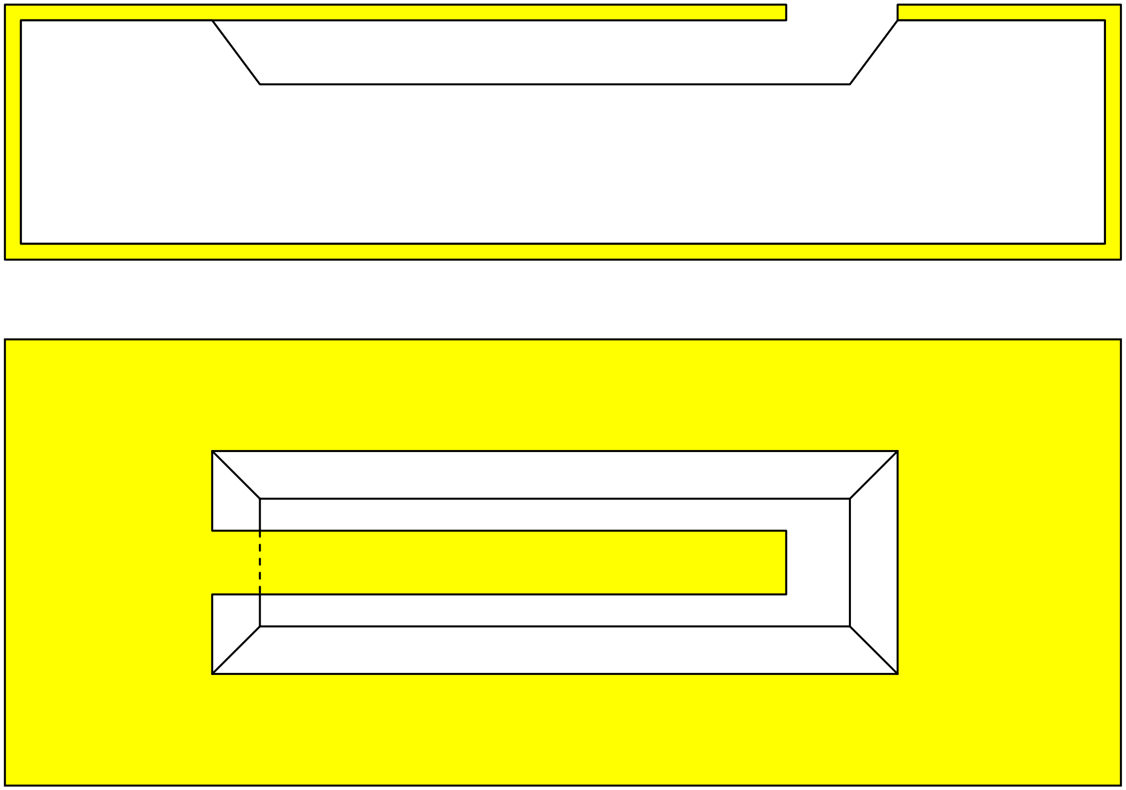
The Process – Lab 1

- Pattern Transfer
  - Deposit photoresist
  - Expose on contact aligner
  - Plasma etch using SF_6 chemistry
  - Strip resist



The Process – Lab 2

- KOH Undercut Etch
  - 20%, 80C



KOH Etching

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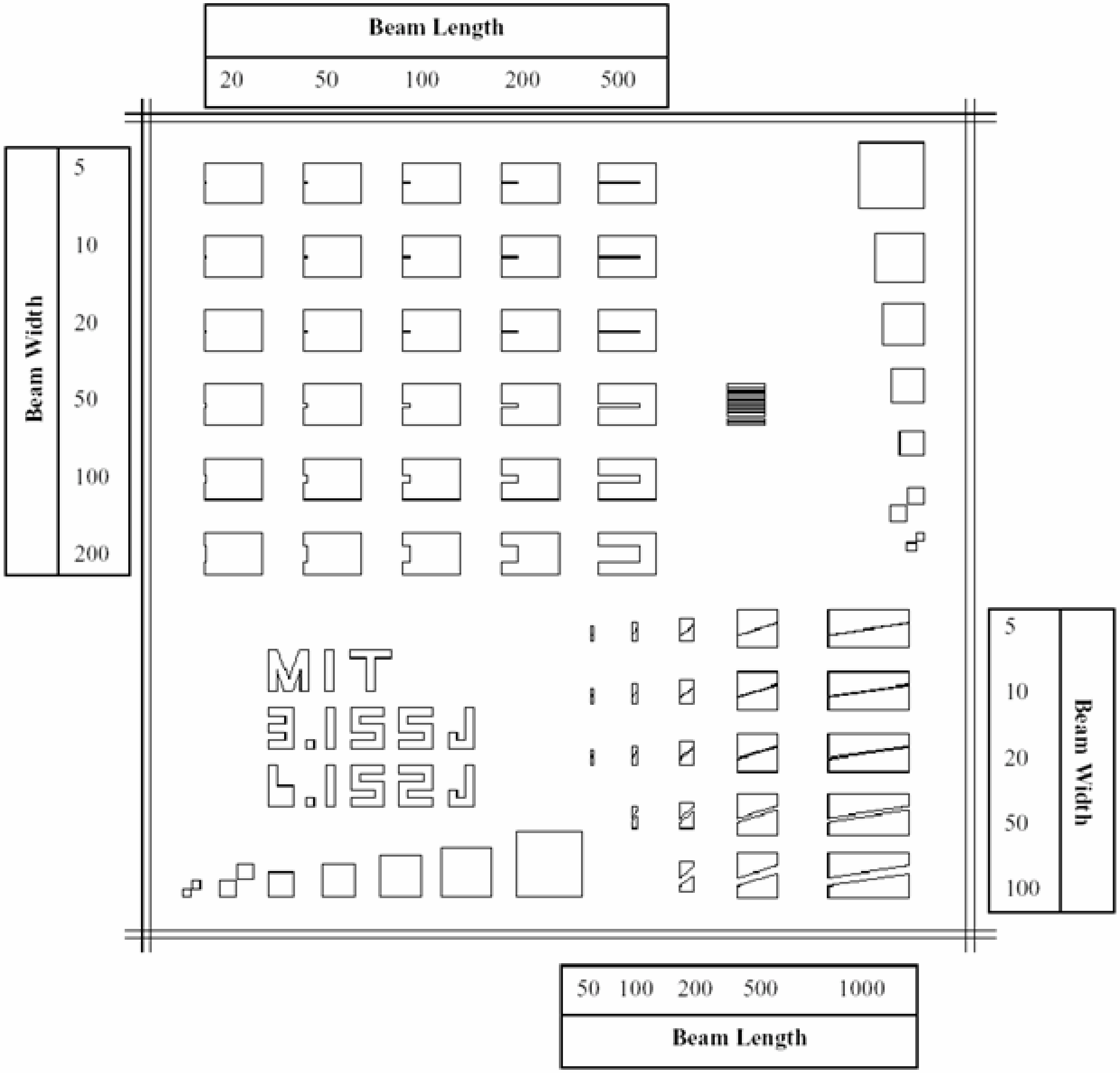
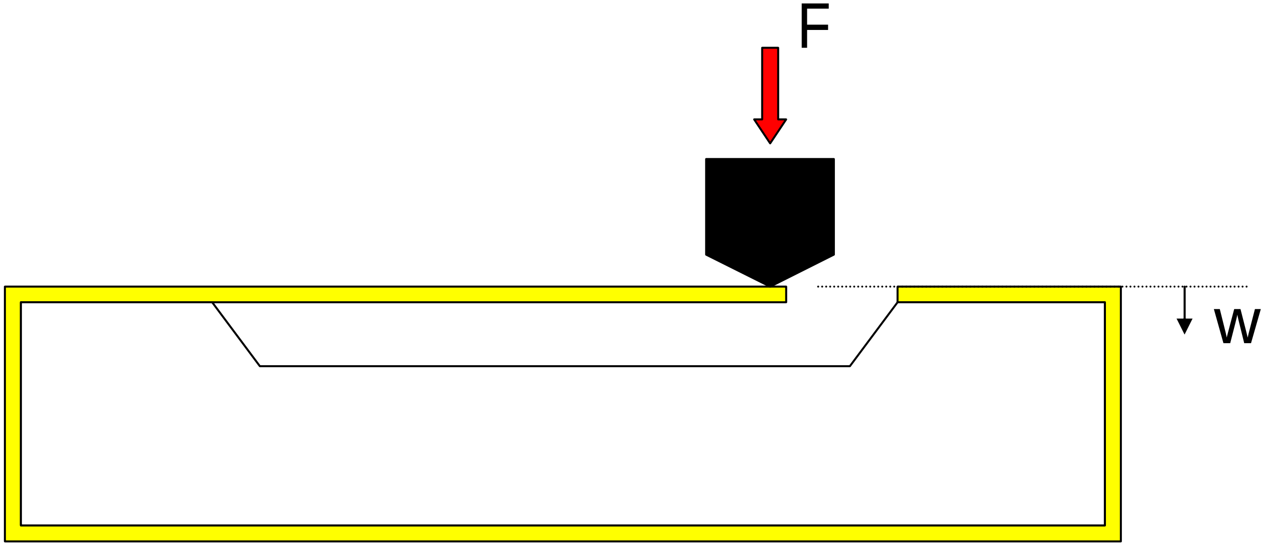
The Mask


Beam Length
20
50
100
200
500
Beam Width
5
10
20
50
100
200
MIT
3.155J
6.152J
5
10
20
50
100
Beam Width
50
100
200
500
1000
Beam Length

The Process – Lab 3

- Break the wafer into die
- Mount the die on a metal plate
- Test using the Hysitron Nanoindenter



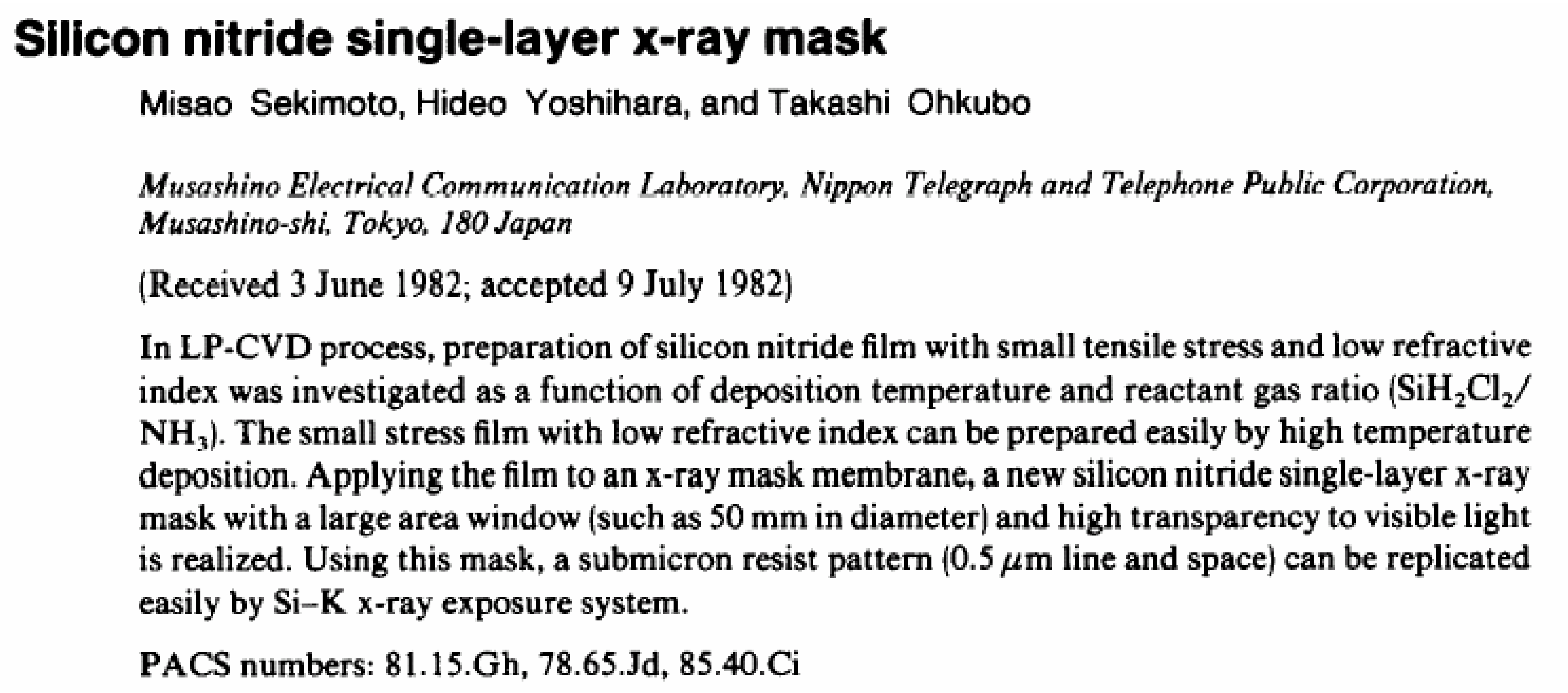
Hysitron Nanoindenter

Figure removed for copyright reasons.

Figure found at www.hysitron.com

- Load
  - Resolution <1nN
  - Noise Floor: 100nM
  - Drift: 50 nN/min
- Displacement
  - Resolution: 0.0002nm
  - Noise Floor: 0.2nm
  - Drift: <0.05 nm/sec

Silicon-Rich Silicon Nitride



Silicon nitride single-layer x-ray mask

Misao Sekimoto, Hideo Yoshihara, and Takashi Ohkubo

Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Musashino-shi, Tokyo, 180 Japan

(Received 3 June 1982; accepted 9 July 1982)

In LP-CVD process, preparation of silicon nitride film with small tensile stress and low refractive index was investigated as a function of deposition temperature and reactant gas ratio (SiH_2Cl_2/NH_3). The small stress film with low refractive index can be prepared easily by high temperature deposition. Applying the film to an x-ray mask membrane, a new silicon nitride single-layer x-ray mask with a large area window (such as 50 mm in diameter) and high transparency to visible light is realized. Using this mask, a submicron resist pattern (0.5 μm line and space) can be replicated easily by Si–K x-ray exposure system.

PACS numbers: 81.15.Gh, 78.65.Jd, 85.40.Ci

Sekimoto, Journal of Vacuum Science and Technology, 1982

CVD Process

Figure removed for copyright reasons.

Figure found in Sekimoto, S., H. Yoshihara, and T. Ohkubo. "Silicon Nitride Single Layer X-Ray Mask." *Journal of Vacuum Science and Technology* 21, no. 4 (Nov./Dec. 1982): 1017-1021.

$$3SiH_2Cl_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$$

Increase ratio of SiH_2Cl_2 to NH_3
Film becomes 'Silicon-Rich' (SiN_x)

Measure Tensile Stress

Figure removed for copyright reasons.

Figure found in Sekimoto, S., H. Yoshihara, and T. Ohkubo. "Silicon Nitride Single Layer X-Ray Mask." *Journal of Vacuum Science and Technology* 21, no. 4 (Nov./Dec. 1982): 1017-1021.

Correlation with Refractive Index

Figure removed for copyright reasons.

Figure found in Sekimoto, S., H. Yoshihara, and T. Ohkubo. "Silicon Nitride Single Layer X-Ray Mask." *Journal of Vacuum Science and Technology* 21, no. 4 (Nov./Dec. 1982): 1017-1021.

Other Information

Figure removed for copyright reasons.

Figure found in Sekimoto, S., H. Yoshihara, and T. Ohkubo. "Silicon Nitride Single Layer X-Ray Mask." *Journal of Vacuum Science and Technology* 21, no. 4 (Nov./Dec. 1982): 1017-1021.